

# Energy Efficient Dynamic Cluster Algorithm for Ad Hoc Sensor Networks

Dali Wei and H. Anthony Chan

*Department of Electrical Engineering, University of Cape Town, South Africa*

**Abstract** — An important issue in ad hoc sensor networks is the limited energy supply within network nodes. Therefore, power consumption is crucial in the routing design. Cluster schemes are efficient in energy saving. This paper proposes a new algorithm called dynamic cluster in which energy in the entire network is distributed and unique route from the source to the destination is designed. In this algorithm, energy efficiency is distributed and improved by (1) optimizing the selection of clusterheads in which both residual energy of the nodes and total power consumption of the cluster are considered; (2) optimizing the number of nodes in the clusters according to the size of the networks and the total power consumption of the cluster; (3) rotating the roles of clusterheads to average the power consumption among clusterheads and normal nodes; and (4) breaking the clusters and reforming them to compensate the difference of the power consumption in different area. Energy efficiency is also improved by defining a unique route to reduce flooding in route discovery and to avoid duplicate data transmission by multiple routes.

**Index Terms** — ad hoc sensor networks, power consumption, cluster schemes, dynamic cluster algorithm.

## I. INTRODUCTION

Ad hoc sensor networks are self-organizing multihop systems of sensor nodes which can communicate with each other. These systems do not have pre-existing infrastructure but each node can act as a router to relay packets to its neighbors [1, 2].

The nodes in sensor networks are usually battery energy supply based. The large number of nodes in these networks and their abominable work environment are incompatible to energy recharge. Therefore power consumption is an important issue in ad hoc sensor networks. More and more attention today is being paid to energy efficiency of ad hoc sensor networks.

Many researches have been conducted to improve the energy efficiency of sensor networks. The former schemes to improve the energy efficiency for sensor networks can be classified into the following categories [3]:

- 1) Scheduling active and non-active nodes, in which the

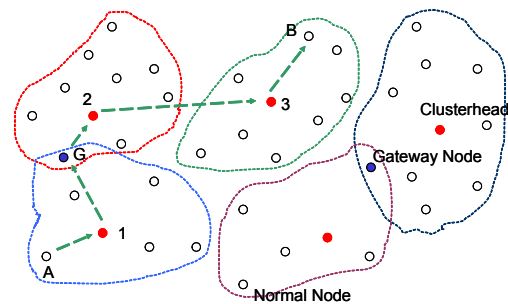
non-active nodes can enter into a lower power consumption state. Yet this method needs high node density, which increases the cost of the network;

- 2) Topology management, in which the route from the source to the destination is optimized and the overhead of the message is reduced. Yet the large number of nodes in ad hoc sensor networks makes this method inefficient;

- 3) Adjusting the power level of the nodes, in which the minimum power can be assigned to each node to reach the expected destination. Yet the lower RF power and the large number of the nodes make this approach inefficient or difficult in realistic application.

- 4) Receiving special messages, in which the node only accepts the special information it is interested in, energy is then saved by receiving less data. Yet this method is difficult to apply in the sensor networks with large number of nodes and complicated topology.

A convenient and efficient approach to address the energy efficiency issue is through the decomposition of a network into clusters. With a cluster scheme, the nodes in the ad hoc network are separated into groups called clusters. The structure of the cluster scheme, as shown in Figure 1, generally consists of three types of nodes: normal nodes, gateway nodes, and clusterheads (CHs).



**Fig. 1. Cluster scheme.**

In each cluster, one node is elected as the clusterhead to act as a local controller (except in [7], where there is no CH), while the rest are gateway nodes and normal nodes. The size of the cluster depends on the RF range (in single-hop cluster) and the number of hops (in multiple-hop cluster) of the cluster.

In Figure 1, suppose there are two nodes A and B, where A intends to send packets to B. A will send the packets to its CH,

CH1 first. Then CH1 transfers the packets to next hop. The gateway node, which belongs to more than one cluster, bridges the CHs in those clusters. The presence of gateway node is not compulsory in cluster schemes. If there is gateway node, such as G in Figure 1, CH1 then relays the packets to CH2 through G. Otherwise, the CH sends the packets to its neighbor CH directly. As shown in Figure 1, there is no gateway node between CH2 and CH3, CH2 then transfers the packets to CH3 directly by itself.

Cluster schemes are hierarchical. Connectivity within a cluster, which only has a small number of nodes, is maintained by periodically exchanging information updates among neighboring nodes about links changes. Therefore when a node sends data to its CH, a route table based protocol may be used. However, if the destination node is in a different cluster, the node will need to discover the route first before sending the packets.

The cluster scheme has many advantages, such as the following [4]:

- 1) Within a cluster, all the normal nodes send their data to the CH. The absence of flooding, multiple routes, or routing loops results in energy saving.
- 2) The backbone network consists only of the CHs, which are far fewer in number than all the nodes in the entire network. Routing with the backbone network is therefore simpler, and requires less storage of routing information and less overhead of the ad hoc network.
- 3) The changes of nodes within a cluster affect only that cluster but not the entire backbone network, which will therefore be robust to these changes.

This paper is organized as follows: Previous energy saving cluster schemes for ad hoc sensor networks and their weaknesses are summarized in Section 2; outline of a new dynamic cluster algorithm and detail design of dynamic cluster algorithm to maximize the energy efficiency is described in Section 3; the summary of the paper and future work is included in Section 4.

## II. ENERGY SAVING IN AD HOC CLUSTER SENSOR NETWORKS

Many cluster schemes have been proposed to improve energy efficiency for ad hoc sensor networks. We summary the existing schemes into three categories: (1) Optimizing the size of the cluster [5-10]; (2) averaging power consumption [5, 11-17], and (3) scheduling active or non-active nodes [18].

### A. Optimizing the size of the cluster

The size of the cluster is an important parameter. If the cluster size is decreased, the power consumption within each cluster is smaller. Yet the number of CHs will then increase, so that the resulting backbone network formed by these CHs will become more complicated. On the other hand, a smaller number of CHs will form a simpler backbone network. Yet that will require larger cluster size, so that the RF power in

each cluster becomes higher or the mutihop route within the cluster becomes more complicated. There is then a tradeoff between the cluster size and the number of CHs. Therefore, optimizing the size of the cluster [5-10] can improve the energy efficiency. There are four methods to optimize the size of the cluster.

The first method is to optimize the organization of the cluster to minimize the sum of distances between the normal nodes and their CHs [5].

The second method is to assign the normal nodes the lowest RF power that is needed for intra-cluster communication and also the CHs the lowest RF power that is needed for inter-cluster communication [6].

The third method involves clusters with different RF ranges. The highest power range is that which is needed to connect all the nodes in the entire network through multihops. A lower power range will form clusters for only the nodes that are close enough to be connected using these lower RF power multihops. Each node may belong to different clusters of different power levels so that different routes are possible by taking different combinations of these RF ranges for each hop. Energy is then saved by optimizing these routes from source to destination [7].

The fourth method uses K-tree and optimizes the value of K to save energy. A K-tree cluster is a framework in which the clustering of nodes is such that any two nodes in a cluster are at most K hops from each other. K-tree clusters are more energy efficient because the normal nodes may send data to its CH through multihops each with lower RF power rather than through a single hop with much higher RF power. In addition, the cluster size can be optimized by choosing the parameter K that results in best energy saving [8-10].

### B. Averaging Power Consumption

The normal nodes in a cluster only transmit their data to their CH and will also relay the data in case of a multihop cluster. In addition to transmitting their data, the CHs are also receiving data from the normal nodes and relaying all these data. The CHs therefore consume more energy than the normal nodes, and when the CHs run out of energy the clusters will break down. Therefore energy can be saved by averaging power consumption among the CHs and normal nodes or balancing the power consumption of each cluster [5].

There are three methods to average power consumption:

The first method is to rotate the role of CHs within the cluster. When the clusters are formed, the role of CHs will be rotated periodically according to the residual energy [11-16]. This method can only distribute power consumption within the cluster.

The second method is to assign each CH the approximately same number of the nodes [14]. Yet in sensor networks, because the processing capability of the sensors is limited, all data will be sent to the data sink for further analysis. Therefore, the sensors near the data sink will encounter higher traffic and

run out of energy earlier. The data sink will then be isolated from the network therefore wasting residual energy in other area nodes. That means assigning each CH the same normal nodes can not distribute the power consumption in the entire network.

While rotating the roles of CHs, if the CHs can be located at the center of the cluster, energy can be saved by avoiding longer transmission range or by reducing hops needed to cover the whole cluster [17].

### C. Scheduling of Active and Non-Active Nodes

There are usually many nodes within the same area in a sensor network, whereas only a smaller number of them are needed to collect the required data in that area.

At a given time, we need only some of the nodes to be active while the rest are turned off. A scheduling approach can be applied to select nodes to be active [18] to achieve energy saving.

### D. Weaknesses of existing cluster schemes

Cluster approach applied in this field does make the power consumption more efficient. Yet weaknesses still exist.

One weakness is the selection of the CHs, some schemes select CHs only according to the residual energy or the ID number of the nodes. Yet both methods cannot guarantee the CHs to be always at the center of the cluster. If the CHs are at the edge of the cluster, extra RF range or hops to cover the whole cluster is needed.

Another weakness is that, because all the data in sensor network are sent to the data sink, the traffic near the data sink is higher. The nodes in these areas will therefore run out of energy earlier. The data sink will then be isolated and as a result, the residual energy stored in the other nodes will be wasted.

The third weakness is that, energy is wasted by flooding in route discovery and duplicated transmission of data by multiple routes from the source to the destination.

All of the weaknesses lead us to propose a new algorithm for ad hoc sensor networks to maximize the lifetime.

## III. DYNAMIC CLUSTER ALGORITHM

Ad hoc sensor networks usually have numerous nodes, which are energy limited and are infeasible to be recharged. Longer lifetime means lower cost. Therefore energy efficiency of ad hoc sensor networks should be maximized.

### A. Overview of dynamic cluster algorithm

This paper proposes a new scheme named dynamic cluster algorithm to maximize the energy efficiency for ad hoc sensor networks.

Dynamic cluster algorithm has two important tasks: (1) optimizing the organization of the clusters; and (2) designing a unique route from source to destination.

Cluster organization is important because it affects the

energy efficiency in ad hoc sensor networks. Dynamic cluster algorithm has five steps in cluster organization: (1) recognizing the neighboring nodes; (2) optimizing the size of the cluster; (3) selecting the CHs; (4) rotating the roles of CHs; and (5) breaking the clusters and then re-organizing them.

Because in ad hoc cluster networks, each CH can act as a router to relay the packets, energy is wasted by discovery and duplicated transmission of data by multiple routes. Therefore, if we can design a unique route from the source to the destination, the energy wasted by route discovery can be reduced and that wasted by duplicated transmission of data can be avoided.

The energy efficiency of ad hoc sensor networks can then be maximized.

### B. Cluster organization

The first task of dynamic cluster algorithm is to optimize the cluster organization. The following describes the five steps in detail.

#### 1) Recognizing the neighboring nodes

In ad hoc sensor networks, although energy can be saved by assigning each individual node a minimum RF power range needed to reach its neighboring nodes, the number of nodes in these networks is too large that make an assignment infeasible. We therefore, assign the same RF power range to all the normal nodes. Yet when a node becomes an initiator or is selected as a CH, it will be assigned a higher value. Then there are only two RF power ranges of the ad hoc sensor network in our algorithm. One is for normal nodes, and another is for initiators and CHs.

We also set the ID of node according to its distance to the data sink. That means the further the nodes are to the data sink, the higher value their ID have (Figure 2).

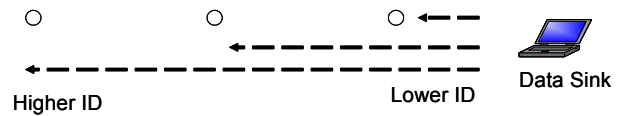


Fig. 2. Node ID in dynamic cluster algorithm.

In reorganization of neighboring nodes, some nodes are automatically selected to become initiators with a probability  $P$ . An initiator is assigned a higher RF power. These initiators send out their own information, including the ID number and residual energy, to their neighboring nodes. When the neighboring nodes receive the information of an initiator, they store that information and will not receive the information from another initiator. These neighboring nodes will then also send their own information back to their initiator which will also store the information. The initiator will now send the information of the ID to the data sink. If the data sink cannot find any ID number of any nodes, it will ask those nodes to join in the nearest initiator.

This step is completed when all the nodes in the network

have joined the initiators. The data sink can check when they have completed.

### 2) Optimizing the size of the cluster

The size of the cluster is an important parameter, which will affect the power consumption and the complexity of the topology of the backbone network. That means the optimized will depend on the size of the whole network.

For example, there are two sensor networks (a) has 200 nodes and (b) has 2000 nodes. If the cluster sizes in these networks are the same, the backbone of network (b) will be more complicated than that of network (a). Power consumption will be higher in the backbone network (b) because of more flooding in route discovery and more overhead of the packets. Therefore the cluster size in network (b) should be larger than that in network (a).

Because all data in a sensor network are sent to the data sink, the clusters near the data sink encounter higher traffic. Then the clusters near the data sink in the same network will encounter higher power consumption owing to their higher traffic. From the result of [3], the area nearer the data sink has 17% more power consumption than that of the area outside the data sink in the network. Therefore the sizes of the clusters with different distances from the data sink will need to be adjusted to compensate for these differences.

We propose a convenient method to calculate the power consumption based on the number of hops, as shown in Figure 3, in which the node 4 is selected as a CH. This example only considers the power consumption on transmitting packets.

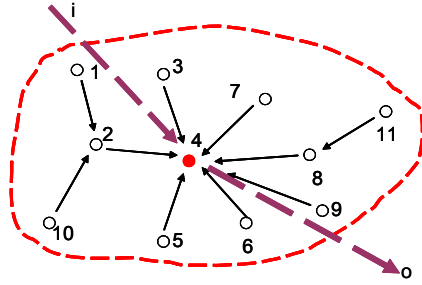


Fig. 3. Power consumption on transmitting data within a cluster.

We assume the following that: (1) all the normal sensors have 1 unit RF power range, whereas the CHs have 3 units RF power range; (2) the generation data rate of each node is 1 unit; (3) the bit rate of the normal nodes is constant; (4) the data transferred to its CH by other CH are  $i$  units.

In Figure 3, the total number of hops within the cluster is 13 (node 1 needs 2 hops to send the data to its CH through node 2, the hops of other nodes are also counted in this way). The total number of the nodes within the cluster is 11. Then the total power consumption on packets transmission of the cluster is:

$$13 \times 1^2 + (i+11) \times 3^2, \quad (1)$$

where  $13 \times 1^2$  is the power consumption on transmitting or

transferring the data to the CH within the cluster, 1 is the RF range of each hop of normal nodes, 2 is the range coefficient;  $(i+11) \times 3^2$  is the power consumption on transferring the total packets to next hop by CH, in which 11 is the packets generated by the nodes within the cluster,  $i$  is the packets transferred to this CH by other CHs, 3 is the RF power range of the CH, and 2 is the range coefficient.

The aim of dynamic cluster algorithm aims at distributing the power consumption among the clusters, which means all clusters have the same lifetime. Then the total energy stored in the cluster should be proportional to the total power consumption of this cluster, this relationship is shown in equation (2).

$$\frac{N_i}{A_i r^2 + (I_i + N_i) R^2} \approx \frac{N_{i+1}}{A_{i+1} r^2 + (I_{i+1} + N_{i+1}) R^2} \quad (2)$$

where  $N_i$  is the number of the node in the cluster,  $A_i r^2 + (I_i + N_i) R^2$  is the total power consumption of the cluster.

The step of deciding the cluster size is almost completed simultaneously with the generation of the first turn CHs (which will be explained in the following section) in step 3.

### 3) Selecting the CHs

After the clusters have formed been in the above two steps, one needs to select the CHs of the cluster. Many previous schemes elect or rotate CHs according to the residual energy or ID number of the node. Yet if a CH is at the edge of the cluster, the nodes will need more extra RF range or hops to send the packets to their CHs, energy will then be wasted, which will be explained in Figure 4.

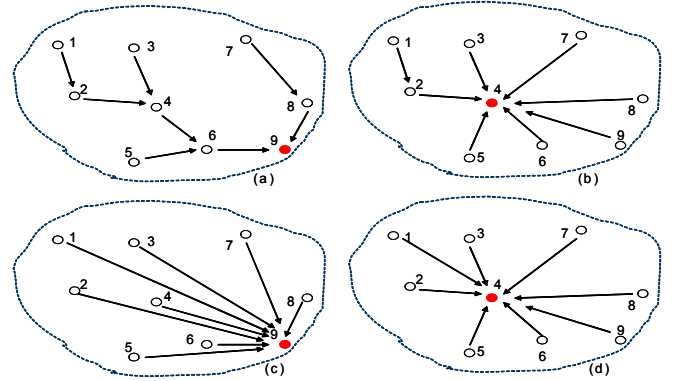


Fig. 4. Energy is wasted if CH is at edge of the cluster.

There are four clusters a, b, c, and d in Figure 4, each cluster has 9 nodes. Two methods of selecting the CHs are shown in the figure. The first method is to select the node 9 as the CH in cluster a and c, the second is to select node 4 as the CH in cluster b and d.

Cluster a and b are multiple-hop clusters. The total number of hops of cluster a is 18 (If node 1 sends message to its CH, the route is  $1 \rightarrow 2 \rightarrow 4 \rightarrow 6 \rightarrow 9$  (4 hops), if node 3 sends message to CH, the route is  $3 \rightarrow 4 \rightarrow 6 \rightarrow 9$  (3 hops), the numbers of hops

of other nodes are also calculated in this way.) Yet in cluster b, the total number of hops of the cluster is only 9. Therefore, energy saving can be achieved in cluster b by reducing the hops.

Cluster c and d are single-hop clusters. From Figure 4, the normal node in cluster c need higher RF power compared with that of the nodes in cluster d. Therefore, energy saving can be achieved in cluster d by reducing the RF power.

Setting the CH at the center of the cluster can save energy. However the residual energy of the nodes should also be considered. The nodes with lower residual energy can not be selected as CHs.

During the recognition step, the information of routes and residual energy is stored in the nodes. The rule of CH selection of multi-hop clusters in sensor networks is then given by Equation (3).

$$CH = \alpha \times hops + \beta \times residualenergy \quad (3)$$

From Equation (3), the selection of a CH from candidate nodes is determined by two parameters: the total numbers of hops from all the normal nodes to the candidate CH and the residual energy of the candidate CH. Here,  $\alpha$  and  $\beta$  are the influence factors of these two parameters. Optimizing  $\alpha$  and  $\beta$  can optimize the selection of CHs.

#### 4) Rotating the roles of CHs

Because the CHs have more burden compared with normal nodes and will run out of energy more quickly, which will then break down the clusters. The power consumption therefore should be distributed among the CHs and normal nodes. The periodical rotation of the roles of CHs in dynamic cluster algorithm is according to Equation (3).

At the end of each CH period, the CH will get the result of Equation (3) of each node in the cluster. A new CH of next period will then be selected according to these results.

#### 5) Breaking the clusters and re-organizing

From Equation (3), the node at the center of the cluster will be selected more frequently as the CH. These nodes then consume energy more quickly and the CH will move to the edge of the cluster. Energy will then be wasted by more hops.

In this algorithm, we break the clusters and reorganize them after some periods of CHs to distribute the energy in the entire network.

At the end of each cluster period, the node with highest residual energy (usually are the nodes at the edge of the cluster) will be set as an initiator. Yet if it gets an announcement as an initiator from a neighboring node, it will then give up being an initiator and another node will be selected. These high residual energy nodes will then be set at the center of the cluster during the next cluster period.

Therefore, the time slots of the whole network are separated into two tiers, as shown in Figure 5. The lifetime of the whole network is separated into cluster periods. One cluster period is separated into several subperiods, called CH periods.

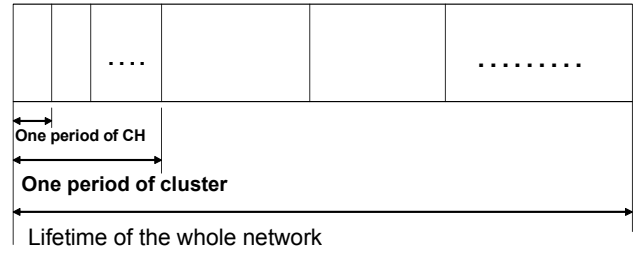


Fig. 5. Time slots of dynamic cluster algorithm.

#### C. Defining a unique route

In ad hoc sensor networks, the large number of nodes makes the topology of the network complicated. Though cluster scheme can alleviate this problem, energy is still wasted by flooding and duplicated transmission of data, as show in Figure 6. Therefore, a unique route from the source to the destination can save extra energy.

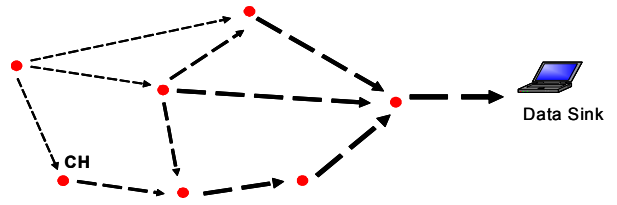


Fig. 6. Different traffic density in the network.

In this algorithm, a unique route from the source to the destination is designed by two rules: (1) Within the RF power range of the CH, only the CH with the lowest ID can receive the data. By this rule, not only the flooding of route discovery can be reduced, but the multiple routes can be avoided.

As shown in Figure 7, let CH4 represents the CH of cluster 4. CH1, CH2, CH3, and CH5 are also defined in this way. Suppose that CH4 wants to send packets to data sink, CH2 and CH3 are available within its RF power range. With this rule, only CH2 will receive the packets, the unique route can then be determined.

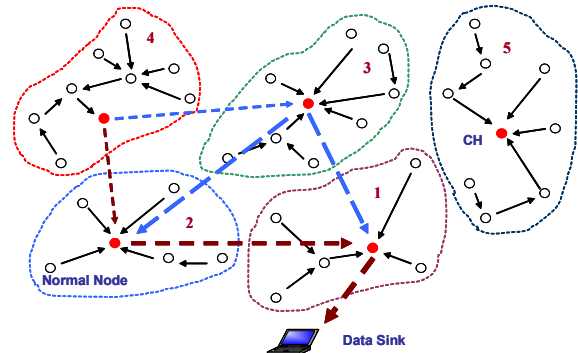


Fig. 7. Lowest ID CH receives the data.

Yet if CH2 has lower residual energy, then CH2 cannot receive the packets. CH3 will then relay the packets for CH4.

So, the first rule of designing the unique route should be



optimized: (2) if the residual energy of the CH is lower than one value; the CH that receives the packets is determined by Equation (4).

$$CH = m \times ID + n \times residual\ energy, \quad (4)$$

where ID and residual energy of the node are two parameters.

If only one CH is available within the RF power range of the CH, then this CH must of course receive the packets. As shown in Figure 7, if CH2 wants to send data to the data sink and only CH1 is covered within its RF range, then CH1 must accept and relay the data.

By these two rules, the unique route can be determined and optimized. More energy saving can be achieved.

#### IV. SUMMARY

Energy efficiency is a crucial issue of ad hoc sensor networks, in which the large number of nodes and the abominable work environment are incompatible to energy recharge.

This paper proposes a scheme, called dynamic cluster algorithm, to maximize energy efficiency. Dynamic cluster algorithm has two objectives: distributing the power consumption in the entire networks and designing a unique route from the source to the destination. The energy efficiency of sensor networks will then be maximized by (1) optimizing the selection of CHs by considering both total power consumption of the cluster and the residual energy of the nodes; (2) optimizing the size of the clusters by considering the different power consumption according to the different traffic in the network and the total energy stored in the clusters; (3) distributing the power consumption among the CHs and the other nodes in the whole network; (4) breaking and reforming clusters to keep the CHs at the center of the clusters and the power consumption balance among the clusters, and (5) designing a unique route from the source to the destination to reduce flooding in route discovery and to avoid the duplicated data transmission by multiple routes.

Further work will focus on the performance evaluation of dynamic cluster algorithm.

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**Dali Wei** received his BSc. and MSc. at University of Electronic Science and Technology of China in 2000 and 2003, respectively and is currently a PhD candidate in the Department of Electrical Engineering, University of Cape Town, R. S. A. He became a Member of IEEE in 2004.

**H. Anthony Chan** (M'94-SM'95) received his PhD in physics at University of Maryland, College Park in 1982 and then continued post-doctorate research there in basic science.

After joining the former AT&T Bell Labs in 1986, his work moved to industry-oriented research in areas of interconnection, electronic packaging, reliability, and assembly in manufacturing, and then moved again to network management, network architecture and standards for both wireless and wire line networks. He designed the Wireless section of the year 2000 state-of-the-art Network Operation Center in AT&T. He was the AT&T delegate in several standards work groups under 3rd generation partnership program (3GPP). During 2001-2003, he was visiting Endowed Pinson Chair Professor in Networking at San Jose State University. In 2004, he joined University of Cape Town as professor in the Department of Electrical Engineering. Prof. Chan is Administrative Vice President of the IEEE CPMT Society and has chaired or served numerous technical committees and conferences. He is a distinguished speaker of the IEEE CPMT Society and has been in the speaker list of the IEEE Reliability Society since 1997.